EFFECT OF CURING ON ROUGHNESS DEVELOPMENT OF CONCRETE PAVEMENTS

Mustaque Hossain, Ph.D., P.E.*
Zahidul Q. Siddique
Kansas State University
Department of Civil Engineering
Manhattan, KS 66506
Tel. No. (785) 532-1576
Fax No. (785) 532-7717
E-mail: mustak@ksu.edu

and

William H. Parcells, Jr., P.E.
Kansas Department of Transportation
Materials & Research Center
2300 Van Buren
Topeka, KS 66611
Tel. No. (785) 291-3846
Fax No. (785) 296-2526
E-mail: billp@ksdot.org

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* Corresponding Author

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ABSTRACT

This paper deals with the results of a study of effect of curing on as-constructed smoothness and subsequent, roughness development of Portland Cement Concrete Pavements (PCCP) in Kansas. Ten test sections on five newly built PCCP projects on Interstate routes 70 and 135 were selected. At each site, one section was cured with a double application of curing compound compared to single application currently specified. Some sections were instrumented with thermocouples to collect temperature data at the bottom of PCCP slab during construction. Large temperature gradient between the top and the bottom of the PCCP slab were observed during concrete placement. Double curing compound application tends to decrease this temperature gradient. Periodic longitudinal profile data was collected by a South Dakota-type Profiler on each wheel path of both driving and passing lanes and were later reduced to International Roughness Index (IRI) statistic. Analysis of Variance (ANOVA) was performed to compare mean IRI values with respect to the curing compound application rate. It was found that single curing compound application results in lower as-constructed IRI values, but double application helps to decrease roughness development in the long run, possibly due to lower differential autogenous volume change of concrete.

INTRODUCTION

Curing is the process of maintaining satisfactory moisture content and temperature in the concrete for a definite period of time. Hydration of Portland cement is a long-term process and requires water and proper temperature. Therefore, curing allows continued hydration and consequently, continued gains in concrete strength. Once curing stops, the concrete dries out, and the strength gain stops. If the concrete is not cured and is allowed to dry in the air, it will gain about 50% of the strength of continuously cured concrete (*1*). If it is cured for 3 days, it will reach about 60% strength of continuously cured concrete, while 80% strength can be achieved by 7-day curing.

Methods of curing concrete fall broadly into three categories (*2*):

(i) Those which minimize moisture loss from the concrete by covering it with a relatively impermeable membrane;
(ii) Those which prevent moisture loss by continuously wetting the exposed surface of the concrete; and
(iii) Those, which keep the surface moist and at the same time, raise the temperature of the concrete, thereby increasing the rate of strength gain.

The first practice involving curing compounds is currently followed by the concrete-paving industry though the second practice was prevalent before World War II (*3*). Curing compounds are liquids which are usually sprayed directly onto concrete surface and which then dry to form a relatively impermeable membrane that prevents moisture loss. This is usually an efficient and cost-effective method of concrete. Curing compounds are generally formulated from a wax emulsions, acrylic emulsions, chlorinated rubbers, synthetic and natural resins, and from Polyvinyl Acetate (PVA) emulsion (*2*). A search of the Pre-Qualified List (PQL) of approved curing compounds by the Kansas Department of Transportation (KDOT) yielded 18 products from seven different manufacturers. Wang et al. (*4*) provided an excellent state-of-the art of the curing compounds.

PROBLEM STATEMENT

Currently KDOT allows curing with a liquid membrane-forming curing compound on freshly placed Portland Cement Concrete Pavement (PCCP) slab as per AASHTO M-148. M-148, Class A, Type 2 (white pigmented) compound is most commonly used. Although curing compounds and membrane curing process have been criticized severely in the recent past (*5*,6), KDOT has been effectively using this method for a long time. Currently KDOT requires a minimum four days of curing so that the pavement achieves a third-point test modulus of rupture of 2.59 MPa (375 psi) before it could be opened to construction traffic. ACI committee 308 recommends curing till the concrete achieves 70% of its design strength. In the 1980's KDOT had a specified minimum curing period of six days. However, the period was reduced since the Portland cement available now is much finer than those used in the past and appears to develop strength much earlier (7). When curing compound application started as a wartime substitute during 2nd world war, no attention was paid to an important aspect of curing- control of thermal stress by regulating early temperature and moisture changes in the concrete slab (3). Subsequent research has produced mixed results (3,6). Currently early–age random cracking on concrete pavements has become a problem (4). The issue is now one of the most-discussed items in PCC research and construction.

KDOT is yet to experience any early age slab cracking on concrete pavements. However, the curing issue has surfaced in conjunction with rapid loss of smoothness on some newly built concrete pavements in Kansas. It has been hypothesized that nonuniform temperature rise in fresh concrete and evaporation of water from the top contribute to "as-built" curling (8). This "as-built" curling is known to contribute to excessive roughness of PCC pavements (8,9). The effectiveness of curing compound is judged to be a factor affecting the curling of slabs during construction. If the curing is proper, such curling could be minimized (10).

OBJECTIVE

The objective of this study was to examine the effect of curing on initial smoothness and roughness development of Portland cement concrete pavements in Kansas.

TEST SECTIONS

Ten (10) PCCP sections on five different projects, built in the summer and fall of 2000 and 2001 and shown in Table 1, were selected as test sections in this study. All of these sections were built with the new Kansas Quality Control/Quality Assurance (QC/QA) specifications. The specifications provide incentives/disincentives for 28-day compressive strength and thickness based on Percent Within Limits (PWL). All test sections consist of 32 continuous slabs (i.e. 160 m long) and are located on both lanes in one direction. The pavements are jointed plain concrete pavements with 5-meter joint spacing and doweled joints, and are located on Interstate routes 70 and 135. All sections have 100-mm stabilized drainable subbase, known as bound drainable base (BDB) in Kansas, and 150-mm lime-treated subgrade. Most of the subgrade materials are fine and plastic. Sub base stabilization was done with cement and cement-fly ash binder and was drainable. A drainable base is defined as the one with a minimum of 303 m/day (1000 ft/day) permeability. The 28-day compressive strength of BDB materials was variable and ranged from 0.90 to 4.44 MPa.

Table 1 shows the slab thickness for the test sections. Two of the I-70 sections, located near Paxico (PTS-1 and PTS-2) have the highest thickness (320 mm), while two I-135 sections, located in Salina (NSTS-1 and NSTS-2) have the lowest thickness (250 mm). Both I-70 and I-135 are 4-lane divided highways. The test sections on each site are adjacent to each other and were built on the same day. All test sections were constructed in summer from mid-June to early August. The maximum air temperature on the day of construction was the highest (108o F) for the 2001 Salina test sections (New Salina test sections) and the lowest was for the 2000 Topeka test sections (87o F). The minimum temperature on the day of construction (67o F) was also recorded at this site. The temperature differentials on the days of construction were similar and varied from 21o F for the Paxico test sections to 28o F for the New Salina test sections.

A single coat of curing compound was applied on the sections designated as "1", and the sections designated as "2" received two coats of curing compound. White pigmented curing compound (wax based), meeting AASHTO M-148, Class A, Type 2 requirements, was used for curing application. For single application, the compound was applied at approximately 1 liter/ 3.7 square meter of the surface. Carter Water's Envirocure W-3 was used on the Paxico, Wamego and New Salina test sections where as W.R. Meadows' Sealtight 1610 Kansas White curing compound was used on the other sections. Table 2 shows the properties of these compounds. Both are wax-based, Class A compounds and satisfied all required KDOT criteria. However, the Sealtight Kansas White has a much higher density and lower drying time than Envirocure W-3. Moisture loss for 1610 Kansas White is almost half of that for Envirocure W-3.

Table 3 tabulates the concrete mixture design information. Although two different contractors built the projects, the mixture designs are somewhat similar. Two different compositions of aggregates were used in the concrete- sixty percent fine and 40% coarse aggregates were used for concrete in six (6) test sections. All other sections had 55% fine and 45% coarse aggregates. Concrete on all sections were air-entrained. The water-cement ratio varied from 0.41 on the New Salina test section to 0.49 on the Paxico test section. All projects used Type I/II Portland cement. The cement content was the highest for the Topeka test sections. The Wamego sections had the highest 3-day modulus of rupture value (4.3 MPa). All sections surpassed the Lower Specified Level (LSL) for 28-day compressive strength of 27 MPa (3,915 psi), but the sections cured with W.R. Meadows 1610 Kansas White curing compound achieved much higher 28-day compressive strength. This contrast is evidently true for the Paxico and Topeka test sections where cement contents and water-cement ratios were comparable.

INSTRUMENTATION AND DATA COLLECTION

Each test section was instrumented with thermocouples to collect temperature data at the bottom of the PCC slab. The top of the slab temperature was collected with a hand-held, RayTek Infrared thermometer. Temperature during construction was monitored hourly at two different sites. At Wamego test section "1," (WTS-1) paving started at around 10.30 AM, and the maximum temperature gradient of 13.3^{o} C between the top and bottom of the freshly placed slab was observed at 2:30 PM, almost 4 hours later. The top and bottom reached about the same temperature at about 7:00 PM. On the second test section (WTS-2), paving started at about 12:30 PM and the maximum temperature gradient of 9.4^{o} C occurred at around 2:30 PM, only 2 hours after the start. This section received double application of curing compound and the data shows that the maximum temperature gradient was about 4^{o} C lower than the single application of curing compound.

At the New Salina test section "2" (NSTS-2), paving started at 9:45 AM and the maximum temperature gradient of 15.6^{o} C happened at 3:00 PM. For NSTS-1, paving started at 10:45 AM and the maximum temperature differential of 16.1^{o} C was recorded at 2:00 PM. Although NSTS-2 had a slightly lower temperature gradient, difference between the two sections was not as prominent as in the Wamego test sections. Both test sections had the temperature gradient of 15.6^{o} C, and the top and the bottom reached the same temperature at around 7:00 PM. It is to be noted that the day of construction of these test sections was extremely hot. A maximum air temperature of 42^{o} C (108^{o} F) was recorded at a nearby weather station.

It is to be noted that two other test sections were also instrumented on I-70 near 2000 Paxico test sections, and data was collected. Both sections were paved in late afternoon. Because of excessive ambient temperature, the contractor decided to use double application of curing compound on both sections. The highest temperature gradient recorded on this site was about 24^{o} C (75^{o} F).

After construction, profile data was collected periodically. As–constructed data was collected 2 to 3 weeks after construction before opening the sections to traffic. After sections were opened to traffic, profile data was collected approximately every four months. Profile data was collected by Kansas Department of Transportation (KDOT) South Dakota Profiler. The profiler used in this study was an International Cybernetics Corporation (ICC) profiler with laser sensors as shown in Figure 2. The sensors measure the distance from the vehicle body to the pavement surface. An accelerometer is used to compensate for the vertical movement of the vehicle body. Profiler collects data at approximately 75 mm (3 inch) interval. Profile measurements for this study were done on both wheel paths of both lanes (driving and passing), and three replicate runs were made.

DATA ANALYSIS

International Roughness Index (IRI) was used as summary statistic. IRI values were computed from the profile data collected by the RoadRuf software (*11*) developed by University of Michigan Transportation Research Institute (UMTRI). As-constructed IRI values for all sections are shown in Figure 3. It is to be noted that these IRI values represent the average IRI of both wheel paths and lanes with three replicate runs on each wheel path. The figure shows that the New Salina sections had the lowest as-constructed IRI. For all sections except Wamego, as-constructed IRI values for sections with single application of curing compound are lower than the IRI values for sections with double application.

Table 4 and Figure 4 show the variation of IRI values with respect to time. For summer 2000 sections (Figure 4(a)), almost all sections exhibit definite patterns and some of the variations could be attributed to the seasonal changes. IRI values for section TTS-1 were the highest for all cases. Topeka test sections (TTS-1 & 2) have higher grade than any other sections. It is to be noted here that, 8-month data for PTS-1 and PTS-2 were not available as those sections were used as work-zone during that time period. The results also indicate that the roughness increase for the PTS sections were the lowest. However, Summer 2001 sections (Figure 4(b)) do not exhibit the same behavior as summer 2000 sections for the first 8 months. For Wamego section, roughness decreased with time. The reason behind this is, because of high as-constructed IRI value, pavement of this section was ground with diamond grinder. After 18 months, IRI values for the sections in Topeka and Salina (TTS and STS) with double curing compound were much lower than the single curing compound sections. This may indicate that the double application of curing compound is beneficial in the long run. During field measurements, double curing compound application was found to decrease the temperature differential between the top and the bottom of the slab in fresh concrete by about 1.2 to 3.9^0 C compared to a single application of curing compound.

Statistical Analysis

Analysis of Variance (ANOVA) was performed to examine the effect of variable rate of curing compound application that might affect roughness development expressed in terms of IRI values and to compare the population means of these factors. A statistical software package SYSTAT (*12*) was used for this purpose. The dependent variable used in this study was IRI. The independent variables were: a) Application of curing compound (single application vs. double application); and b) Time (0, 4, 8, 12, and 16 months for Summer 2000 sections and 0,4, and 8 months for summer 2001 sections). The interaction of these factors was also examined. Since two different curing compounds were used, each section was analyzed separately. The model for the experiment is

$$IRI_{ij} = CURING_i + TIME_j + (CURING \times TIME)_{ij} + \varepsilon_{ij} \quad (1)$$

Where, IRI_{ij} =International Roughness Index (m/km);

$CURING_j$ = ith effect of Curing application;

$TIME_j$ = jth effect of Time;

$(CURING \times TIME)_{ij}$ = Interaction of ith effect of Curing Application and jth effect of Time;

ε_{ij} = Error term.

The results of ANOVA are shown in Table 5. All conclusions were drawn at 95% confidence level. The results show that for all three Summer 2000 sections, application of curing compound and time have significant effect on the mean IRI values. IRI values for sections cured with single application of curing compound are significantly higher than those for sections cured with double application. For Summer 2001 sections, curing compound does not have any significant effect on the mean IRI values, although time significantly affects the mean IRI values on these two sections. Interaction between application of curing compound and time was significant for the Salina and Paxico sections.

The means of the response variable at different time periods was compared by the least squares means (LSMean) approach. This technique weighs the estimates of each treatment or treatment combination effect equally, but not each observation (*13*). LSMean model deals with the average of individual treatment measurements and for treatment combination, it gives unequal weight to each observation. The effects of one or more factors on treatments for comparison are eliminated since it estimates the average of the averages. It may be mentioned here that increased sample size increases the precision of the estimate of the treatment combination mean response (*13*). LSMEAN analysis was used to compare the effect of the factors in this study. It shows that for two of the Summer 2000 test sections, Topeka and Salina, mean as-constructed IRI values for sections cured with double application of curing compound were higher than those for sections cured with single application. However, the scenario is just opposite for the rest of the time periods, as shown in Figure 5 for the Salina test section. The sections cured with double application of the curing compound sustained as-constructed smoothness better than the section with a single application of curing compound. However, this trend is not statistically significant for the Paxico test section. It is to be noted that the Paxico and the Summer 2001 test sections were cured with a different curing product than the Salina and Topeka test sections. This can be explained as follows:

It is well known that curling and warping of concrete pavement slabs are affected by vertical temperature and moisture gradients. In general, during placing pavement slab concrete, no significant moisture gradient exists up to the time when final set takes place, but a temperature gradient has already been built up (*3*). Little real compensation for temperature gradients, therefore, is brought about by moisture gradients during the first day, since the concrete has already set in a heat-distorted structure before moisture effects come into play. It is also true that evaporation of moisture does exert a direct compensatory influence on the curling of the slab (*3*). This may very well be responsible for higher smoothness on the test sections built with single application of curing compound with higher water loss (Envrocure W-3) and single application of curing compound. However, the real factor that causes long-term difference in curling and warping, and eventually long-term roughness is the autogenous shrinkage , or the contraction in absolute volume of the cement-water system during hydration if cement. In the 1920's some searchers have observed that a residual upward curl remains in concrete slabs dried from both top and bottom, even when no temperature gradient exists due to differential autogeneous shrinkage (*3*). Differential autogenous shrinkage may happen due to (i) heterogeneity the concrete and (ii) different rates of hydration througout the depth of the slab induced by temperature and moisture gradients. However, this differential volume change can be controlled if the concrete can be kept moist continuously after finishing. Now on both Salina and Topeka test sections, when single application of curing compound was applied, the initial loss of moisture from the top and from the bottom in the relatively open-graded drainable base was compensating the curling being developed by the temperature gradient, thereby resulting in initial lower roughness (IRI) values on those sections. However, the sections with double application of curing compounds had no such compensation due to lower moisture loss, and resulted in large upward curl and higher roughness (IRI) values. These sections eventually though will have lower differential autogenous shrinkage and lower roughness in the long run. However, it is to be remembered that the PCCP roughness is also significantly affected by a host of design and construction features (*14*).

As mentioned earlier, application of curing compound does not have any significant effect on the as-constructed smoothness and the roughness development of the Summer 2001 test sections. This may be due to the fact all 2001 sections had the same contractor and the same curing compound on all sections. Also, IRI data only up to eight months are available. It is expected that these sections would exhibit different roughness development trends after a year or so.

CONCLUSIONS

Based on this study, the following conclusions can be made:

1. A large temperature gradient (as high as 24^{o} C) between the top and bottom of the concrete pavement slab can build up during concrete placement in Kansas.

2. Double curing compound application tends to decrease the temperature differential between the top and the bottom of the slab in freshly placed concrete pavement slab. The temperature gradients were 1.2 to 3.9^{0} C lower when compared to the slabs with a single application of curing compound.
3. Curing compound application significantly affects the as-constructed smoothness and subsequent loss of smoothness (roughness development) on concrete pavements.
4. Single application of curing compound usually results in lower roughness initially, but double application helps to decrease roughness development in the long term possibly due to lower differential autogenous volume change.

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REFERENCES

1. Mamlouk, M., S., and J. P. Zaniewski. Materials for Civil and Construction Engineers. Addison Wesly Longman Inc., California, 1999.
2. QCL Group. *Technical Note: The Curing of Concrete.* QCL Group, Milton, Australia, March 1999.
3. Rhodes, C.C. Curing Concrete Pavements with Membranes. Research Report for Highway Research Report No. 145, Michigan State Highway Department, East Lansing, August 1950.
4. Wang, K., J.K. Cable and G. Zhi. Investigation into Improved Pavement Curing Materials and Techniques: Part I. Final Report, Iowa DOT Project TR-451, Center for Transportation Research and Training, Iowa State University, Ames, April 2002.
5. Senbetta, E. "Concrete Curing Practices in the United States," *Concrete Internationa*l, Vol.10 No.11, November 1988, pp. 64-67.
6. Wang, J., R.K. Dhir and M. Levitt. Membrane Curing of Concrete: Moisture Loss. Cement and Concrete Research, Vol. 24, No. 8, 1994, pp. 1463-1474.
7. Personal Communication with John B. Wojakowski, P.E., Concrete Research Engineer, Kansas Department of Transportation, Topeka, July 8, 2002.
8. FHWA. *Midwestern Pavement News*. Issue 2000-01, Federal Highway Administration Midwest Resource Center, Olympia Fields, Illinois, May 2000.
9. Byrum, C.R. Analysis of LTPP JCP Slab Curvature Using High Speed Profiles. In *Transportation Research Record No. 1730,* Transportation Research Board, National Research Council, Washington D.C., 2000, pp. 1-9.
10. Mather, B. "Curing Compound," *Concrete International: Design and Constructio*n, Vol. 12, No. 2, February 1990, pp. 40–41.
11. Road Profile Analysis Software. http://www.umtri.umich.edu/erd/roughness/rr.html. Accessed June 29, 2002.
12. SPSS Inc., Manual of SYSTAT 9 Statistics II, Chicago, 1999.
13. G. A. Milliken and D. E. Johnson. *Analysis of Messy Data*. Lifetime Learning Publications, Belmont, Calif., 1984, pp. 150-158.
14. Siddique, Z.Q., M. Hossain, J. Devore and W.H. Parcells, Jr. Curling and Smoothness of Portland Cement Concrete Pavements. Paper being Offered for

Presentation at the 82nd Annual Meeting of the Transportation Research Board, National Research Council, January 12-16, 2003.

TABLE 1 Details of Test Sections

Test Section Name	Section Symbol	Route	Construc-tion Date	Slab Thickness (mm)	Grade (%)	Curing Compound Used
Paxico 1	PTS-1	I-70	07/25/00	320	0.0	Carter Water Envirocure W-3
Paxico 2	PTS-2	I-70	07/25/00	320	0.4	Carter Water Envirocure W-3
Salina 1	STS-1	I-135	07/26/00	280	0.1	W.R. Meadows 1610 Kansas White
Salina 2	STS-2	I-135	07/26/00	280	0.1	W.R. Meadows 1610 Kansas White
Topeka 1	TTS-1	I-70	07/25/00	290	4.0	W.R. Meadows 1610 Kansas White
Topeka 2	TTS-2	I-70	07/25/00	290	4.0	W.R. Meadows 1610 Kansas White
Wamego 1	WTS-1	I-70	06/13/01	300	0.5	Carter Water Envirocure W-3
Wamego 2	WTS-2	I-70	06/13/01	300	0.3	Carter Water Envirocure W-3
New Salina 1	NSTS-1	I-135	07/07/01	250	0.5	Carter Water Envirocure W-3
New Salina 2	NSTS-2	I-135	07/07/01	250	0.5	Carter Water Envirocure W-3

TABLE 2 Curing Compound Properties

Product Name	Base	Vehicle	Consistency	Test Duration (hrs)	Density (kg/liter)	Moisture Loss (kg/cm^2)	Dry Time (hours)	Non Volatiles	4-hour color
Carter Water Corp. Envirocure W-3	Wax	Water	Satisfactory	72	0.8208	0.38	4	26.28	Yes
W.R Meadows Sealtight 1610 Kansas White	Wax	Water	Satisfactory	72	0.9993	0.20	1/2	24.3	Yes

TABLE 3 Concrete Mix Design Parameters

Section	% Aggregate in Mix		% Air	Water-Cement Ratio	Cement Content (Kg/m^3)	28-day Core Compressive Strength (MPa)	3-Day Modulus of Rupture (MPa)
	Coarse	Fine					
PTS-1	40	60	6.50	0.49	330	31.7	4.10
PTS-2	40	60	6.50	0.49	330	31.7	4.10
STS-1	45	55	7.00	0.45	325	44.5	3.30
STS-2	45	55	7.00	0.45	325	44.5	3.30
TTS-1	45	55	7.50	0.47	335	41.4	3.92
TTS-2	45	55	7.50	0.47	335	41.4	3.92
WTS-1	40	60	6.50	0.42	314	36.0	4.30
WTS-2	40	60	6.50	0.42	314	36.0	4.30
NSTS-1	40	60	5.25	0.41	312	32.5	3.60
NSTS-2	40	60	5.25	0.41	312	32.5	3.60

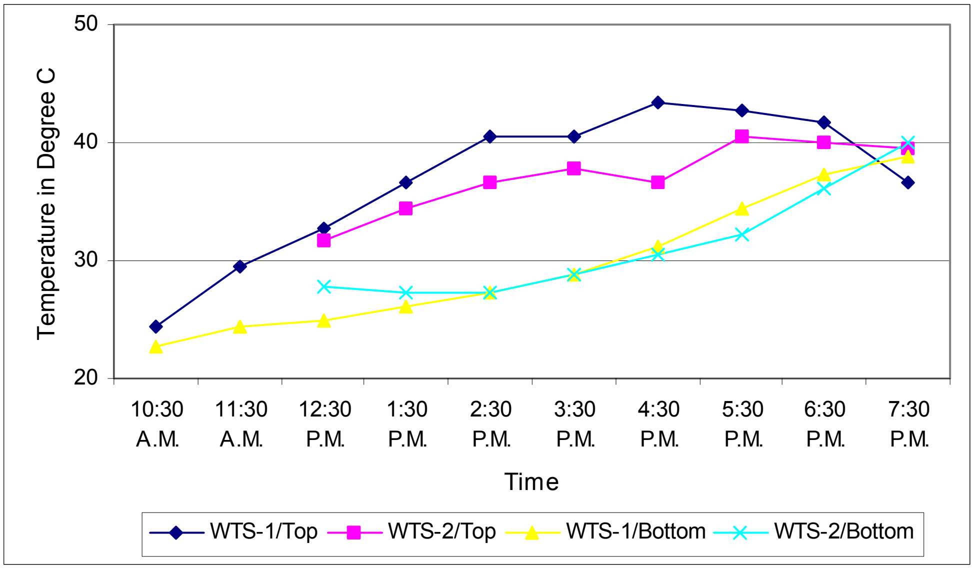
TABLE 4 Mean IRI Values for Different Sections with Respect to Time

Time	Test Section	Mean IRI (m/km)			
		Curing Application			
		Single		Double	
		DL#	PL+	DL	PL
As-constructed	Paxico	1.00	1.02	0.99	1.11
	Salina	1.33	1.33	1.42	1.43
	Topeka	1.44	1.20	1.58	1.74
	Wamego	1.57	1.33	1.49	1.39
	New Salina	0.80	0.85	0.81	0.88
4-Month	Paxico	0.85	0.83	0.99	1.21
	Salina	1.14	1.18	1.18	1.04
	Topeka	1.48	1.55	1.26	1.08
	Wamego	1.35	1.23	1.40	1.36
	New Salina	0.88	0.94	0.9	0.9
8-Month	Paxico*	-	-	-	-
	Salina	1.58	1.63	1.40	1.43
	Topeka	2.2	2.45	1.87	1.87
	Wamego	1.14	1.01	1.27	1.08
	New Salina	0.76	0.87	0.80	0.77
12-Month	Paxico	1.1	1.01	1.41	1.27
	Salina	1.53	1.51	1.45	1.39
	Topeka	1.72	1.55	1.64	1.55
16-Month	Paxico	1.12	0.99	1.35	1.19
	Salina	1.46	1.47	1.36	1.24
	Topeka	1.79	2.08	1.51	1.46
Average		1.31		1.29	

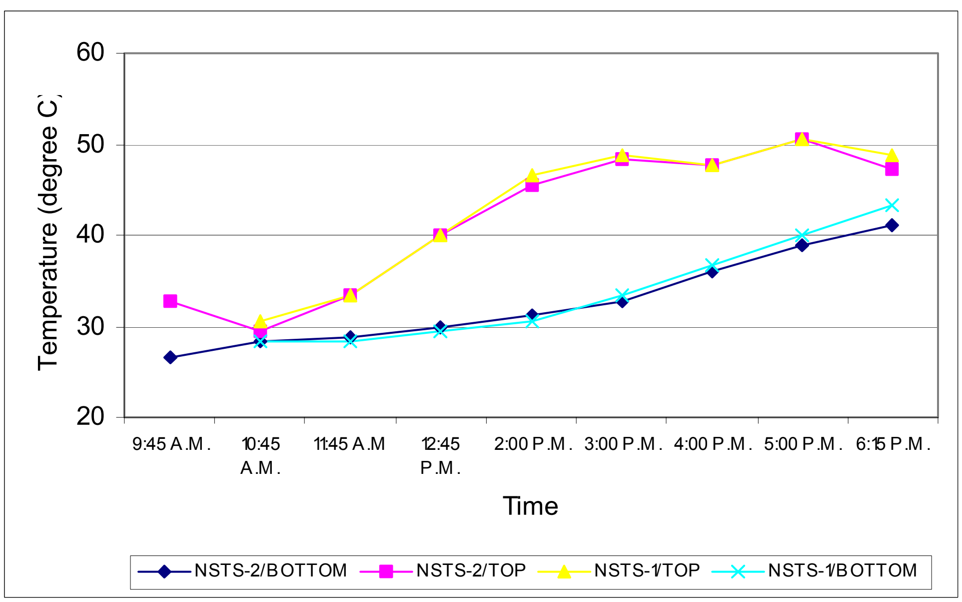
* Served two-way traffic
\# Driving Lane
\+ Passing Lane

TABLE 5 Effect of Different Factors on Mean IRI Values

Test Section	Effect on Mean IRI Values		
	Curing Application	**Time**	**Interaction**
Paxico	Different	Different	Different
Salina	Different	Different	Different
Topeka	Different	Different	Equal
Wamego	Equal	Different	Equal
New Salina	Equal	Different	Equal



a) Wamego Test Section



b) New Salina Test Section

FGURE 1 Temperature Variation of Freshly Placed Concrete Slabs for Different Sections

FIGURE 2 KDOT South Dakota-Type Profiler

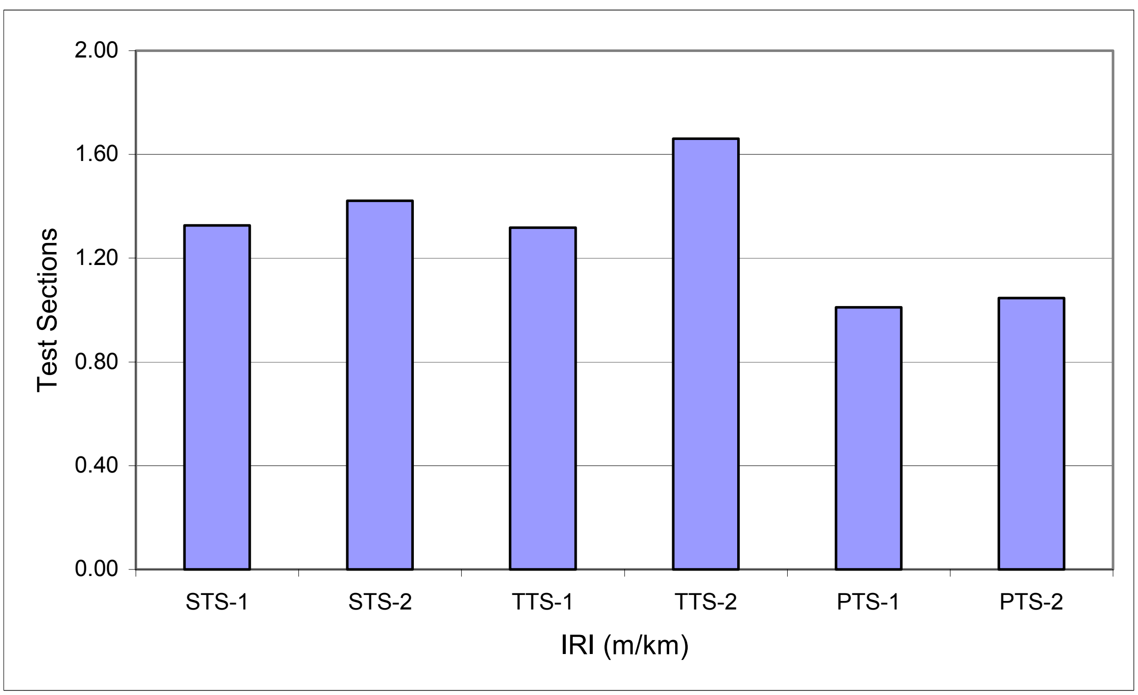
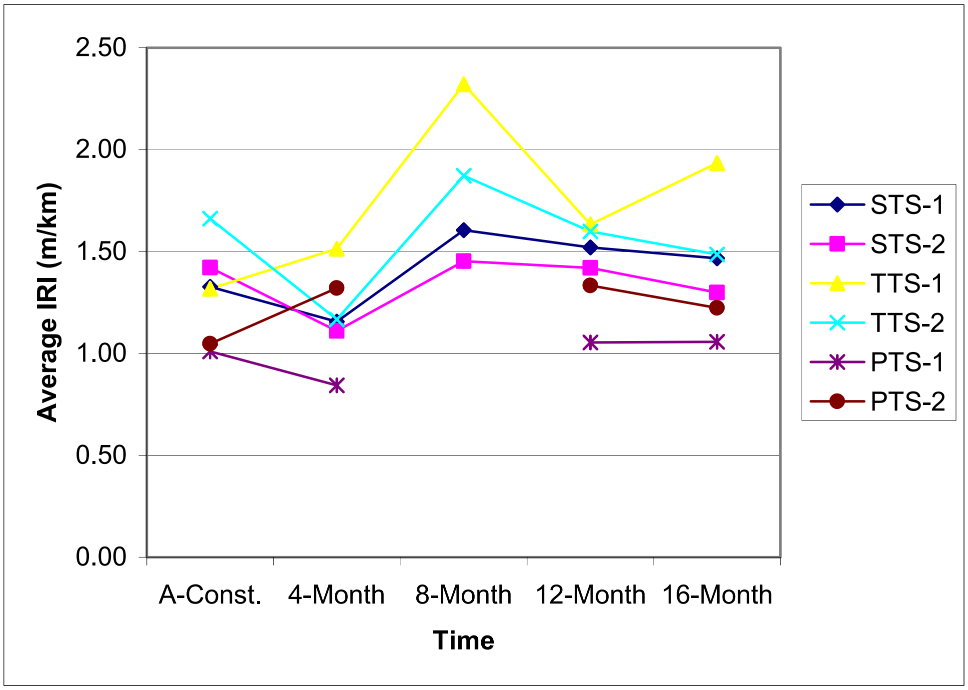
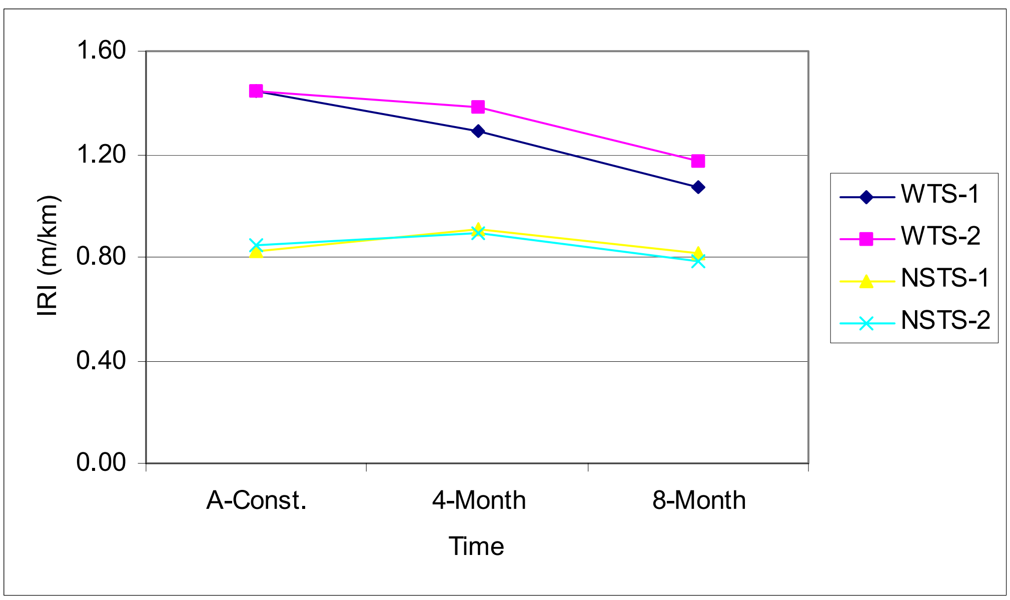


FIGURE 3 As-Constructed IRI values for Different Test Sections



(a) Summer 2000 Sections



(b) Summer 2001 Sections

FIGURE 4 Variation of IRI with respect to Time

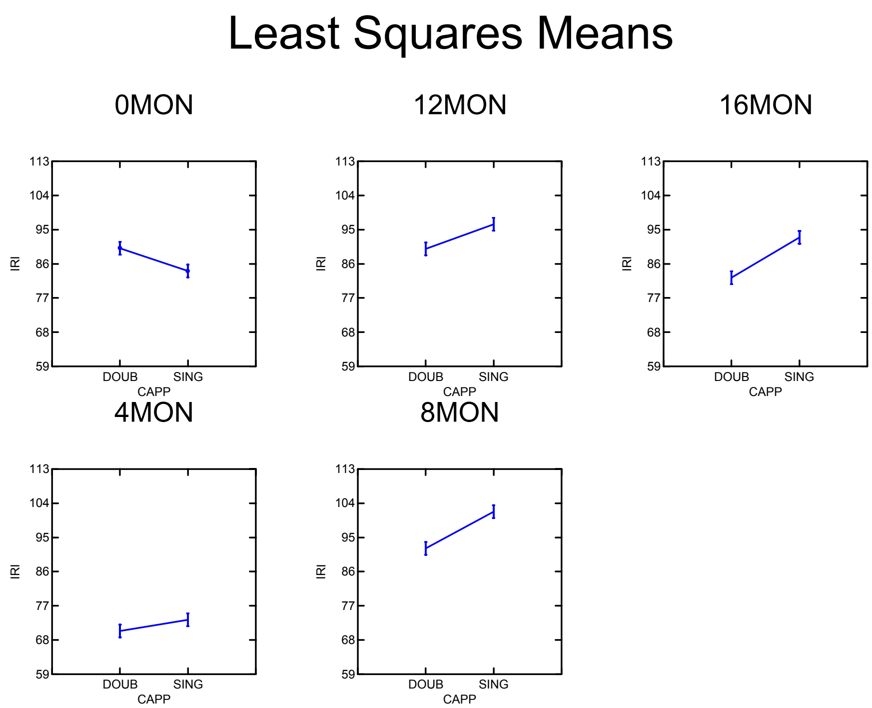


FIGURE 5 Statistical Interaction Effect of Curing Compound Application and Time at the Salina Test Section